A MODULAR ARMORED VEHICLE SYSTEM

The present invention relates to a modular armored vehicle system for use in producing armored combat vehicles. More specifically, the present invention relates to a modular armored vehicle system comprising an armored combat vehicle chassis in combination with a plurality of composite armor plates for absorbing and dissipating kinetic energy from high velocity armor-piercing projectiles.

Modular armor mounting systems and the advantages thereof are known in the prior art and are discussed e.g. in US Patent 5,421,238.

As described therein, the modern battlefield has become a place of ever increasing lethality demanding ever increasing protection. For combat vehicles increasing protection levels implies increasing the amount of armor on the vehicle which increases the vehicle weight. However, the response time available to position a military force and its vehicles from a home base has decreased, and the ability to maintain a large standing military force in foreign lands has diminished. The present protocol is to have vehicles which can be air lifted to a remote location and the vehicles deployed from that location. Air lifting heavy armored vehicles has become increasingly difficult and in the case of the heaviest vehicles is impossible.

One solution to the present problem is to have a vehicle with a relatively light weight, strong, powerful chassis which can be easily air lifted to the desired location and the needed armor protection attached to the chassis to provide the necessary threat protection. The armor and the vehicle could be transported separately and assembled at a remote site before going into battle.

Armor applied to a vehicle chassis is described therein as being of two main types; applique armor and modular armor. Applique armor is defined therein as being sheets of armor attached to the vehicle chassis to form an armor skin; while

in a modular construction armor, housings containing a threat attenuating filler are attached to the vehicle chassis.

The present invention to a new concept of modular composite applique armor, i.e. modular elements of composite armor which form the armored skin of the vehicle as described herein.

Modular armor is designed to take the full force of enemy projectiles leaving the vehicle intact and allowing the crew and vehicle to continue functioning until the vehicle can be brought to a safe area for repair. It is one of the strengths of modular armor that it can be repaired, modified, changed or added to the vehicle as needed.

As stated, while said patent relates to a modular armor mounting system, it is directed to a mounting structure for attaching standard steel plates to a combat vehicle chassis and thus while said patent relates to providing a lightweight chassis that can be air lifted to a desired location, it does not solve the problem of the weight inherent in steel plated armor sufficient for dealing with the kinetic energy of high velocity armor-piercing projectiles of various calibers.

Thus, as is known, a steel plate having a weight of 90 kg/m^2 is barely sufficient to stop a threat according to standard NIJ level 4, and it is known that it is necessary to provide a steel plate having a weight of more than 110 kg/m^2 to deal with a projectile of 12.7 mm and when one is dealing with a projectile of 14.5 mm the steel plate capable of stopping the same must weigh about 150 kg/m^2.

In contradistinction to this prior art approach to armor combat vehicles, it has now been found according to the present invention that it is possible to provide a modular armored vehicle system characterized by lighter weight also when fully armored and in combat use thereby resulting in less motor strain and better motor and vehicle performance.

Thus, according to the present invention there is now provided a modular armored vehicle system comprising an armored combat vehicle chassis having a plurality of openings and a plurality of composite armor plates for absorbing and dissipating kinetic energy from high velocity, armor-piercing projectiles, each of said plates being adapted for attachment to said chassis and sized to cover at least one of said openings wherein each of said plates comprises a single layer of bodies which are directly bound and retained in plate form by a solidified material wherein a majority of each of said bodies is in direct contact with at least four adjacent bodies, wherein the solidified material and the plate are elastic and wherein said bodies have a specific gravity of at least 2.4 and are made of a ceramic material.

As is known, steel and aluminum protection are effective against shrapnel and low energy projectiles. They originally were completely ineffective against threats such as 14.5 mm projectiles and projectiles of greater dimensions unless the material was thickened however this caused an overburdening on the vehicle either inhibiting or eliminating its ability to be used for amphibious and aviational uses. In addition such a vehicle required a larger, stronger engine. Furthermore, the added weight of the steel protection necessitates the reduction of comparable weight through reduction of combatants or combat material.

Heretofore, ceramic plates were not used as a stand alone armor for armored vehicles because of its susceptibility to fractures and cracks and it was required to pass rigorous, periodical testing. Assuming that a solution based on regular ceramic plates is found, generally this can be based on hot press silicon carbide or metal phase silicon carbide although other ceramic materials can be used and the thickness of the backing has to be at least equal to the thickness of the ceramic plate.

According to the present invention, as stated above it has now been discovered that composite armor utilizing ceramic pellets in a solidified material, wherein the solidified material and the plate material are elastic provides for the

first time the ability to design a vehicle with ceramic protection due to the high elasticity, high fracture immunity and high durability vis-a-vis vandalism, bending and twisting achievable with the composite panels suggested herein.

Furthermore, as is known, steel is very ineffective against armor penetrating projectiles. In order to protect against such a threat the steel plates must be very thick and this results in an increase in weight as discussed above.

On the other hand, ceramic plates, while more effective than steel against armor penetrating projectiles, are breakable and less elastic.

In contradistinction, the plates used in the present invention characterized by high elasticity and high immunity to fracture and cracking creates a new solution enabling the design of a modular vehicle that is much lighter, easily transportable by air overseas, adaptable to amphibious uses and most importantly much lighter on the battle field without effecting battlefield performance.

The term "elasticity" as used herein relates to the fact that the plates according to the present invention are bent when a load is applied thereto however upon release of said load the plate returns to its original shape without damage.

In preferred embodiments of the present invention, said plate constitutes an outer, impact receiving panel of a multi-layered armor panel further comprising an inner layer adjacent to said outer plate, comprising a second ballistic panel, wherein said outer plate serves to deform and shatter an impacting high velocity armor-piercing projectile and said second ballistic panel is adapted to retain any remaining fragments from said projectile and from said bodies and to absorb remaining energy from said fragments.

In further preferred embodiments of the present invention, said plate constitutes an outer impact receiving panel, a second ballistic panel as defined above as well as comprising a third backing layer for absorbing trauma.

Preferably, said third layer is formed of a polymeric matrix composite with reinforcing fibers or from metals of high modulus of elongation and tearing strength such as aluminum and titanium.

It is to be noted that a thin layer of steel plate having a plurality of holes in order to reduce its weight could also be used for said third layer, although the use of the above mentioned metals is preferred.

In especially preferred embodiments said reinforcing fibers are selected from the group consisting of carbon fibers, aramid fibers and glass fibers.

In especially preferred embodiments of the present invention there is provided a modular armored vehicle system for combat vehicles comprising a plurality of interchangeable plates, a first plurality of said plates having pellets sized to absorb and dissipate kinetic energy from high velocity armor-piercing 12.7 mm – 14.5 mm projectiles, a second plurality of said plates having pellets sized to absorb and dissipate kinetic energy from high velocity armor-piercing 14.5 mm – 30 mm projectiles, and a third plurality of said plates having pellets sized to absorb and dissipate kinetic energy from high velocity armor-piercing projectiles of over 30 mm, said plates being interchangeably mountable on said combat vehicle chassis for covering the plurality of openings provided in said chassis for said purpose.

In especially preferred embodiments of the present invention, said bodies are ceramic pellets having at least one axis of at least 9 mm length.

In the most preferred embodiments of the present invention, the pellets in said plates have a regular geometric cross-sectional area. The term "regular geometric" as used herein refers to forms that are regular forms such as circles and ovals as well as forms that repeat themselves including star shapes, polygonal cross-sectional shapes and multiple repeating patterns of alternating straight and curved segments characterized in that a cut along said regular geometric

cross-sectional area or perpendicular thereto results in two surfaces which are symmetrical.

In especially preferred embodiments of the present invention, the pellets in said plates have at least one convexly curved outwardly facing end face.

Especially preferred for use in the present invention are pellets having at least one circular cross section and pellets having substantially cylindrical prismatic bodies with convexly curved end faces are most preferred.

In the plates of the present invention, the preferred arrangement of the pellets is such that the pellets in said plates each have at least one axis of at least 9 mm length and each of a majority of said pellets is in direct contact with at least six adjacent pellets in the same layer to provide mutual lateral confinement therebetween and said at least one axis is preferably substantially perpendicular to the outer, impact-receiving face of said plate.

The present invention is a modification of the inventions described in US Patents 5,763,813; 5,972,819; 6,289,781; 6,112,635; 6,203,908; 6,408,734; and 6,575,075 and in WO-A-9815796 and WO-99/60327 the relevant teachings of which are incorporated herein by reference since while said earlier patents teach composite armor which can be utilized in the present invention none of them teach or suggest the concept of a modular armored vehicle system for use in producing armored combat vehicles wherein the armor panels serve as stand-alone rather than add on protection for an armored vehicle and are adapted for attachment to an armored combat vehicle chassis to cover openings provided therein.

In US Patent 5,763,813 there is described and claimed a composite armor material for absorbing and dissipating kinetic energy from high velocity, armor-piercing projectiles, comprising a panel consisting essentially of a single internal layer of high density ceramic pellets said pellets having an Al_2O_3 content of at least 93% and a specific gravity of at least 2.5 and retained in panel form by a

solidified material which is elastic at a temperature below 250°C; the majority of said pellets each having a part of a major axis of a length of in the range of about 3-12mm, and being bound by said solidified material in plurality of superposed rows, wherein a majority of each of said pellets is in contact with at least 4 adjacent pellets, the weight of said panel does not exceed 45kg/m^2.

In US Patent 6,112,635 there is described and claimed a composite armor plate for absorbing and dissipating kinetic energy from high velocity, armor-piercing projectiles, said plate consisting essentially of a single internal layer of high density ceramic pellets which are directly bound and retained in plate form by a solidified material such that the pellets are bound in a plurality of adjacent rows, wherein the pellets have an Al_2O_3 content of at least 93% and a specific gravity of at least 2.5, the majority of the pellets each have at least one axis of at least 12 mm length said one axis of substantially all of said pellets being in substantial parallel orientation with each other and substantially perpendicular to an adjacent surface of said plate and wherein a majority of each of said pellets is in direct contact with 6 adjacent pellets, and said solidified material and said plate are elastic.

In WO-A-9815796 there is described and claimed a ceramic body for deployment in a composite armor panel, said body being substantially cylindrical in shape, with at least one convexly curved end face, wherein the ratio D/R between the diameter D of said cylindrical body and the radius R of curvature of said at least one convexly curved end face is at least 0.64:1.

In WO 99/60327 it was described that the improved properties of the plates described in the earlier patent applications of this series is as much a function of the configuration of the pellets, which are of regular geometric form with at least one convexly curved end face (for example, the pellets may be spherical or ovoidal, or of regular geometric cross-section, such as hexagonal, with at least one convexly curved end face), said panels and their arrangement as a single internal layer of pellets bound by an elastic solidified material, wherein each of a majority of said pellets is in direct contact with at least four adjacent pellets and said curved

end face of each pellet is oriented to substantially face in the direction of an outer impact-receiving major surface of the plate. As a result, said specification teaches that composite armor plates superior to those available in the prior art can be manufactured using pellets made of sintered refractory materials or ceramic materials having a specific gravity below that of aluminum oxide, e.g., boron carbide with a specific gravity of 2.45, silicon carbide with a specific gravity of 3.2 and silicon aluminum oxynitride with a specific gravity of about 3.2.

Thus, it was described in said publication that sintered oxides, nitrides, carbides and borides of magnesium, zirconium, tungsten, molybdium, titanium and silica can be used and especially preferred for use in said publication and in the present invention are pellets selected from the group consisting of boron carbide, titanium diboride, silicon carbide, silicon oxide, silicon nitride, magnesium oxide, silicon aluminum oxynitride in both its alpha and beta forms and mixtures thereof.

In US Patent 6,289,781 there is described and claimed a composite armor plate for absorbing and dissipating kinetic energy from high velocity projectiles, said plate comprising a single internal layer of pellets which are directly bound and retained in plate form by a solidified material such that the pellets are bound in a plurality of adjacent rows, characterized in that the pellets have a specific gravity of at least 2 and are made of a material selected from the group consisting of glass, sintered refractory material, ceramic material which does not contain aluminum oxide and ceramic material having an aluminum oxide content of not more than 80%, the majority of the pellets each have at least one axis of at least 3 mm length and are bound by said solidified material in said single internal layer of adjacent rows such that each of a majority of said pellets is in direct contact with at least six adjacent pellets in the same layer to provide mutual lateral confinement therebetween, said pellets each have a substantially regular geometric form and said solidified material and said plate are elastic.

In US Patent 6,408,734 there is described and claimed a composite armor plate for absorbing and dissipating kinetic energy from high velocity, armor-piercing

projectiles, as well as from soft-nosed projectiles, said plate comprising a single internal layer of high density ceramic pellets, characterized in that said pellets are arranged in a single layer of adjacent rows and columns, wherein a majority of each of said pellets is in direct contact with at least four adjacent pellets and each of said pellets are substantially cylindrical in shape with at least one convexly curved end face, further characterized in that spaces formed between said adjacent cylindrical pellets are filled with a material for preventing the flow of soft metal from impacting projectiles through said spaces, said material being in the form of a triangular insert having concave sides complimentary to the convex curvature of the sides of three adjacent cylindrical pellets, or being integrally formed as part of a special interstices-filling pellet, said pellet being in the form of a six sided star with concave sides complimentary to the convex curvature of the sides of six adjacent cylindrical pellets, said pellets and material being bound and retained in plate form by a solidified material, wherein said solidified material and said plate material are elastic.

Said solidified material can be any suitable material, such as aluminum, epoxy, a thermoplastic polymer, or a thermoset plastic.

When aluminum is used as said solidified material an x-ray of the plate shows the formation of a honeycomb structure around the pellets.

While not shown, the panels of the present invention or at least the outer surface thereof can be furthered covered by a thin layer of kevlar, fiberglass, or even aluminum for protection and for concealing the structure thereof.

As stated, the relevant teachings of all of these specifications are incorporated herein by reference.

The invention will now be described in connection with certain preferred embodiments with reference to the following illustrative figures so that it may be more fully understood.

With specific reference now to the figures in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

FIG. 1 is a schematic illustration of an armored vehicle incorporating a panel according to the present invention; and

FIG. 2 is a perspective enlarged view of a small section of an armor panel of the type incorporated in the armored vehicle of FIG. 1.

Referring to FIG. 1, there is seen an armored vehicle 2 wherein a panel 4 of the present invention having a plurality of pellets 6 of substantially cylindrical prismatic bodies 8 with convexly curved end faces 10 as more fully seen with reference to FIG. 2 has been provided in an opening (not shown) of said vehicle 2.

Referring to FIG. 2, there is seen an enlarged segment of one of the panels 4 utilized to cover openings in the vehicle 2 of FIG. 1 wherein said panel comprises a single layer of pellets 6 that are directly bound and retained in plate form by a solidified material 7 wherein a majority of each of said pellets 6 is in direct contact with six adjacent pellets 6' and each of said pellets are substantially cylindrical prismatic bodies 8 with convexly curved end faces 10 said panel further comprises an inner layer 11 adjacent to said outer facing plate 5 comprising a second ballistic panel wherein said outer plate 5 serves to deform and shatter an impacting high velocity armor-piercing projectile 12 and said second ballistic panel 11 is adapted to retain any remaining fragments from said projectile and from said bodies and to absorb remaining energy from said fragments.

As will be seen in preferred embodiments of the present invention said panel 4 is further provided with a third backing layer 13 for absorbing trauma and protecting combatants seated in the vehicle from trauma transmitted through the first two layers of the panel.

Panel 4 is further provided with attachment means 14 for securing said panel to an opening in said vehicle chassis.

In operation the panel 4 of the present invention acts to stop an incoming projectile in one of the three modes of center contact, flank contact and valley contact as described hereinafter.

More specifically, it has been found that the novel armor of the present invention traps incoming projectiles between several pellets which are held in a single layer in mutual abutting and laterally-confining relationship.

An incoming projectile may contact the pellet array in one of three ways:

1. **Center contact.** The impact allows the full volume of the pellet to participate in stopping the projectile, which cannot penetrate without pulverizing the whole pellet, an energy-intensive task which results in the shattering of the pellet. The pellets used are either spheres or other regular geometric shapes having at least one convexly curved end face, said end face being oriented to substantially face in the direction of an outer impact receiving major surface of said plate.

2. **Flank contact.** The impact causes projectile yaw, thus making projectile arrest easier, as a larger frontal area is contacted, and not only the sharp nose of the projectile. The projectile is deflected sideways and needs to form for itself a large aperture to penetrate, thus allowing the armor to absorb the projectile energy.

3. **Valley contact.** The projectile is jammed, usually between the flanks of three pellets, all of which participate in projectile arrest. The high side forces

applied to the pellets are resisted by the pellets adjacent thereto as held by the matrix, and penetration is prevented.

Tables 1 and 2 are reproductions of test reports relating to multi-layer panels according to the present invention incorporating pellets having substantially cylindrical prismatic bodies with convexly curved end faces wherein said pellets have a diameter of 19 mm and a height of 22 mm and said panel is prepared as described in US Patent 6,112,635.

TEST PANEL

Description : PROPRIETARY

Manufacturer: PROPRIETARY
Size : 24.5 x 24.5 in.
Thicknesses : na
Avg. Thick. : na in.

Sample No. : ARRAY-1 / TARGET-1
Weight : 78.3 lbs. (a)
Hardness : NA
Plies/Laminates: NA

AMMUNITION

(1): 20mm Frag. Sim.
(2): 14.5mm B-32
(3):
(4):

Lot No.:
Lot No.:
Lot No.:
Lot No.:

SET-UP

Vel. Screens : 15.0 ft. & 35.0 ft.
Shot Spacing : PER CUSTOMER REQUEST
Barrel No./Gun : 20-30MM / 14.5-1
Obliquity : 0 deg.
Witness Panel : .020"2024-T3 ALUM.

Range to Target : 40.67 ft.
Range Number : 3
Backing Material: NA
Target to Wit. : 6.0in.
Conditioning : 70 deg. F.

APPLICABLE STANDARDS OR PROCEDURES

(1): PER CUSTOMER REQUEST
(2):
(3):

Shot No.	Ammo.	Time sx10-5	Velocity ft/s	Time sx10-5	Velocity ft/s	Avg. Vel ft/s	Vel.Loss ft/s	Stk. Vel. ft/s	Penetration	Footnotes
1	1	487.8	4100	488.0	4098	4099	95	4004	None	
2	2	723.5	2764	723.7	2764	2764	7	2757	None	
3	2	715.8	2794	716.1	2793	2794	7	2787	None	
4	2	714.1	2801	714.4	2800	2800	7	2793	None	
5	2	703.9	2841	704.1	2840	2840	7	2833	None	
6	2	653.1	3062	653.2	3062	3062	7	3055	None	
7	2	640.1	3124	640.3	3124	3124	7	3117	None	
8	2	600.8	3329	601.0	3328	3328	7	3321	Bullet/Spall	

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D.R. Dunn, President
H.P. White Laboratory, Inc.

TEST PANEL

Description : PROPRIETARY

Manufacturer: PROPRIETARY
Size : 24 x 24 in.
Thicknesses : na
Avg. Thick. : na in.

Sample No. : ARRAY-1 / TARGET-2
Weight : 80.9 lbs. (a)
Hardness : NA
Plies/Laminates: NA

AMMUNITION

(1): 14.5mm B-32
(2): 20mm Frag. Sim.
(3):
(4):

Lot No.:
Lot No.:
Lot No.:
Lot No.:

SET-UP

Vel. Screens : 15.0 ft. & 35.0 ft.
Shot Spacing : PER CUSTOMER REQUEST
Barrel No./Gun : 20-30MM / 14.5-1
Obliquity : 0 deg.
Witness Panel : .020"2024-T3 ALUM.

Range to Target : 40.67 ft.
Range Number : 3
Backing Material: NA
Target to Wit. : 6.0in.
Conditioning : 70 deg. F.

APPLICABLE STANDARDS OR PROCEDURES

(1): PER CUSTOMER REQUEST
(2):
(3):

Shot No.	Ammo.	Time sx10-5	Velocity ft/s.	Time sx10-5	Velocity ft/s	Avg. Vel ft/s	Vel.Loss ft/s	Stk. Vel. ft/s	Penetration	Footnotes
1	1	605.3	3304	605.5	3303	3304	7	3297	None	
2	1	589.6	3392	589.8	3391	3392	7	3385	None	
3	2	461.5	4334	461.6	4333	4334	100	4234	None	
4	2	450.8	4437	450.8	4437	4437	102	4335	Bullet/Spall	

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H.P. White Laboratory, Inc.

As will be noted, the first panel which had a size of 24.5 x 24.5 in. and a dynema backing had a weight of only 78.3 lbs. which weight does not include 1.3 lbs. for said soft woven aramid cover and withstood a 20 mm frag. sim projectile and seven out of eight 14.5 mm B-32 projectiles fired at a range of only 40 feet, wherein only the last projectile in which the strike velocity was intentionally raised to a strike velocity of 3,321 ft/s succeeded in penetrating the panel.

In a test carried out in a second panel of similar dimensions and properties, two out of two 14.5 mm B-32 projectiles did not penetrate the panel and only the second of two 20 mm frag. sim projectiles, which second projectile was fired at an intentionally elevated strike velocity of 4,335 ft/s, succeeded in penetrating the panel.

In this context it is to be noted that the army sets a standard of requirements for an armor for stopping a designated projectile at a designated assumed strike velocity. In the above tests the armor withstood projectiles fired at the designated standard strike velocity and only projectiles which were fired at a deliberately elevated strike velocity in order to determine the upper limit of impact resistance penetrated the test panels.

It will be evident to those skilled in the art that the invention is not limited to the details of the foregoing illustrative embodiments and that the present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.